PROPOSED

U.S. Department of Transportation
Federal Aviation Administration

Advisory Circular

Subject:	Airworthiness Criteria for the Installation Approval of a Terrain Awareness and Warning System (TAWS) Approved Under TSO-C151	**Date:** 9/99 **Initiated by:** ANM-110	**AC No:** 25-*XX* **Change:**

1. PURPOSE. This advisory circular (AC) establishes an acceptable means, but not the only means, of obtaining FAA airworthiness approval for the installation of a Terrain Awareness and Warning System (TAWS) that has been approved under Technical Standard Order (TSO)-C151, *Terrain Awareness and Warning System*. The FAA's TSO process is a means for obtaining FAA design and performance approval for an appliance, system, or product; however, the TSO does not provide installation approval. This AC serves to provide guidance for designing an acceptable installation for a TAWS that is compliant with TSO-C151. The guidance provided is specific to installations of these systems on transport category airplanes certificated under 14 CFR part 25 [commonly referred to as part 25 of the Federal Aviation Regulations (FAR)]. It describes the airworthiness considerations for such installations as they apply to the unique features of the TAWS and the interface of the TAWS with other systems on the airplane.

Like all advisory material, this AC is not mandatory and does not constitute a regulation. It is issued for guidance purposes and to outline a method of compliance with applicable airworthiness requirements. Because the method of compliance presented in this AC is not mandatory, the terms "shall" and "must" used in this AC apply only to an applicant who chooses to follow this particular method.

2. RELATED REGULATIONS AND DOCUMENTS.

a. Regulations. 14 CFR parts:

§ 25.1301 *Function and installation*
§ 25.1303 *Flight and navigation instruments*
§ 25.1309 *Equipment, systems, and installations*
§ 25.1321 *Arrangement and visibility*
§ 25.1322 *Warning, caution, and advisory lights*
§ 25.1333 *Instrument systems*
§ 25.1351 *Electrical systems and equipment -- General*

§ 25.1353 *Electrical equipment and installations*
§ 25.1357 *Circuit protective devices*
§ 25.1381 *Instrument lights*
§ 25.1383 *Landing lights*
§ 25.1431 *Electronic equipment*
§ 25.1459 *Flight recorders*
§ 25.1529 *Instructions for Continued Airworthiness*
§ 25.1541 *Markings and placards -- General*
§ 25.1581 *Airplane flight manual -- General*
§ 25.1585 *Operating procedures*

[Proposed regulations]:

§ 91.223 *Terrain awareness and warning system*
§ 121.354 *Terrain awareness and warning system*
§ 121.360 *Ground proximity warning-glide slope deviation alerting system*
§ 135.154 *Terrain awareness and warning system*

b. FAA Advisory Circulars (AC), Orders, and Technical Standard Orders (TSO). The AC's and TSO's listed below can be obtained from the U.S. Department of Transportation, General Services Section, M-443.2, Washington, D.C. 20590.

- AC 20-112, *Airworthiness and Operational Approval of the Airborne Systems to be Used in Lieu of Ground Proximity Warning System*, February 19, 1981.

- AC 20-130A, *Airworthiness Approval of Navigation or Flight Management Systems Integrating Multiple Navigation Sensors,* June 14, 1995.

- AC 20-138, *Airworthiness Approval of Global Positioning System (GPS) Navigation Equipment for Use as a VFR and IFR Supplemental Navigation System*, June 25, 1994.

- AC 25-4, *Inertial Navigation Systems (INS),* February 18, 1966.

- AC 25-10, *Guidance for Installation of Miscellaneous Nonrequired Electrical Equipment*, March 6, 1987.

- AC 25-11, *Transport Category Airplane Electronic Display Systems,* July 16, 1987.

- AC 25-12, *Airworthiness Criteria for Approval of Airborne Windshear Warning Systems in Transport Category Airplanes,* November 2, 1987.

- AC 25-16, *Electrical Fault and Fire Prevention and Protection*, April 5, 1991.
- AC 25.1309-1A, *Systems Design and Analysis*, June 21, 1988.
- AC 25.1581-1, *Airplane Flight Manual*, July 14, 1997.
- AC 90-45A, *Approval of Area Navigation Systems for Use in the U.S. National Airspace System*, February 21, 1975.
- FAA Order 8110.4A, *Type Certification*
- FAA Order 8260.3B, *United States Standard for Terminal Instrument Procedures (TERPS)*
- TSO-C92c, *Airborne Ground Proximity Warning Equipment*
- TSO-C113, *Airborne Multipurpose Electronic Display*
- TSO-C115, *Airborne Navigation Equipment Using Multi-Sensor Inputs*
- TSO-C117a, *Airborne Windshear Warning and Escape Guidance Systems for Transport Airplanes*
- TSO-C129a, *Airborne Supplemental Navigation Equipment Using the Global Positioning System (GPS)*
- TSO C145, *Airborne Navigation Sensors Using the Global Positioning System (GPS) Augmented by the Wide Area Augmentation System (WAAS)*
- TSO-C151, *Terrain Awareness and Warning System*

c. Industry documents.

(1) The Radio Technical Commission for Aeronautics (RTCA) documents listed below are available from RTCA, Inc., 1140 Connecticut Avenue N.W., Suite 1020, Washington, D.C. 20036-4001.

- DO-160D, *Environmental Conditions and Test Procedures for Airborne Equipment*
- DO-161A, *Minimum Performance Standards - Airborne Ground Proximity Warning Equipment*

- DO-178B, *Software Consideration in Airborne Systems and Equipment Certification*
- DO-200A, *Preparation, Verification and Distribution of User-Selectable Navigation Database*
- DO-208, *Minimum Operational Performance Standards for Airborne Supplemental Navigation Equipment Using Global Positioning System*

(2) The Society of Automotive Engineers (SAE) document listed below is available from SAE, 400 Commonwealth Drive, Warrendale, Pennsylvania 15096-0001.

- Society of Automotive Engineers (SAE) Aerospace Recommended Practice (ARP) 4761, *Guidelines and Methods for Conducting the Safety Assessment Process on Civil Airborne Systems and Equipment*
- Society of Automotive Engineers (SAE) Aerospace Recommended Practice (ARP) 4754, *Certification Considerations for Highly Integrated or Complex Aircraft Systems*

3. DEFINITIONS.

a. Alert: A visual, aural, or tactile stimulus presented to attract attention and/or convey information regarding system status or condition.

b. Aural Alert: A discrete sound, tone, or verbal statement used to enunciate a condition, situation, or event.

c. Caution Alert: An alert requiring immediate flightcrew awareness. Subsequent corrective action normally will be necessary.

d. Class A Terrain Awareness and Warning System (TAWS) Equipment: A class of equipment that is defined in TSO C151. As a minimum, it will provide alerts for the following circumstances:

- Reduced required terrain clearance.
- Imminent terrain impact
- Premature descent.
- Excessive rates of descent.
- Excessive closure rate to terrain.
- Negative climb rate or altitude loss after take-off.

- Flight into terrain when not in landing configuration.
- Excessive downward deviation from an ILS glideslope.
- Descent of the airplane to 500 feet above the terrain or nearest runway elevation (voice callout "Five Hundred").

This class of TAWS equipment also must provide a terrain awareness display of the surrounding terrain and/or obstacles relative to the airplane. See TSO C151, Table 11-1, to determine which operating rules and aircraft configurations require Class A TAWS equipment.

e. Class B TAWS Equipment: A class of equipment that is defined in TSO C151. As a minimum, it will provide alerts for the following circumstances:

- Reduced required terrain clearance.
- Imminent terrain impact.
- Premature descent.
- Excessive rates of descent.
- Negative climb rate or altitude loss after take-off.
- Descent of the airplane to 500 feet above the terrain or nearest runway elevation (voice callout "Five Hundred").

This class of TAWS equipment does not require a terrain awareness display of the surrounding terrain and/or obstacles relative to the airplane. See TSO C151, Table 11-1, to determine which operating rules and aircraft configurations require Class B TAWS equipment.

f. Controlled Flight Into Terrain (CFIT): An accident or incident in which the airplane, under the flightcrew's control, is inadvertently flown into terrain, obstacles, or water without sufficient and/or timely flightcrew awareness to prevent the event.

g. Failure: The inability of the equipment or any sub-part of that equipment to perform within previously specified limits

h. False Alert: A warning or caution that occurs when the design terrain warning or caution threshold of the system is not exceeded.

i. Forward Looking Terrain Avoidance (FLTA): A TAWS functional requirement to provide look-ahead terrain and obstacle protection along and below the airplane's lateral and vertical flight path.

j. Hazard: A state or set of conditions that, together with other conditions in the environment, could lead to an accident.

k. Hazardously Misleading Information (HMI). Erroneous information being sent by the TAWS equipment to the terrain display that is presented in a manner that could result in a significant reduction in terrain clearance.

l. Nuisance Alert: An alert that is caused by improper setting of the terrain alerting threshold.

m. Premature Descent Alert (PDA): A warning system's ability to detect when the aircraft is hazardously below the normal (approximately 3 degrees) approach path for the nearest runway, and to provide a timely alert.

n. Required Terrain Clearance (RTC): The minimum requirements for obstacle/terrain clearance as defined by United States Standard for Terminal Instrument Procedures (TERPS) FAA Handbook 8260.3B and the Aeronautical Information Manual (AIM).

o. Terrain Awareness and Warning System (TAWS): A system that provides the flightcrew with sufficient information and alerting to detect a potentially hazardous terrain situation and take effective action.

p. Terrain Awareness Display: A display of the surrounding terrain or obstacle(s) relative to the airplane.

q. Terrain Database: Terrain or obstacle information stored within a TAWS.

r. Time-shared Display. A display that shows terrain information, plus additional information from other systems [e.g., an Electric Flight Instrument System/Navigation Display/Multi-Function Display (EFIS/ND/MFD)].

s. Visual Alert: The use of projected or displayed information to present a condition, situation, or event to the flightcrew.

t. Warning Alert: An alert for a detected terrain threat that requires immediate flightcrew action.

4. BACKGROUND. Controlled flight into terrain (CFIT) has been a principal contributor to commercial jet airplane hull losses and fatalities. Before 1975, the worldwide commercial jet airplane fleet averaged approximately eight CFIT accidents per year. When the original Ground Proximity Warning System (GPWS) was first introduced on aircraft in the mid-1970's, it dramatically reduced accident rates. The GPWS is a computer-based system that, among other things, provides the flightcrew with adequate warning (both aural and visual) of inadvertent contact of the airplane with the terrain or other obstacles, taking into account such items as crew recognition and reaction times.

In 1974, the FAA issued Amendments 121-114 and 135-12 (39 FR 44440, December. 24, 1974), which required that all part 121 certificate holders (i.e., those operating large turbine-powered airplanes) and certain part 135 certificate holders (i.e., those operating large turbojet-powered airplanes) install GPWS equipment approved under TSO-C92c (*Airborne Ground Proximity Warning Equipment*) in their airplanes. (In 1978, the FAA extended this same requirement to part 135 certificate holders operating smaller turbojet-powered airplanes.) That TSO prescribes the minimum performance standards that GPWS equipment must meet to be in compliance with the applicable regulation.

The use of GPWS has not entirely eliminated the problem of CFIT, however, and CFIT accidents continue to occur.

Recent advances in terrain mapping technology have led to the development of a new type of GPWS that provides greater situational awareness to flightcrews. It is designed to help reduce the CFIT accident rate even further by providing additional information and warning to the flightcrew in situations where the airplane may be inadvertently approaching significant rising terrain or a man-made obstruction. There is an increased interest in certifying these systems on transport airplanes due to recent and continuing accidents attributed to CFIT.

a. TSO-C151. The FAA has issued Technical Standard Order (TSO)-C151, *Terrain Awareness and Warning System,* which prescribes the minimum design standards that a Terrain Awareness and Warning System (TAWS) must meet to be identified with the TSO-C151 marking. The TAWS described in the TSO is representative of the "next generation" GPWS. In addition to the standards and test procedures required for the Forward Looking Terrain Avoidance (FLTA) functions, the TAWS incorporates the standards and test procedures for Basic GPWS equipment (as defined in TSO-C92c and in RTCA document DO-161A, *Minimum Performance Standards - Airborne Ground Proximity Warning Equipment).*

For further in-depth information concerning the TAWS' capabilities, refer to TSO-C151.

b. Need for Guidance. The FAA's TSO process is a means of obtaining FAA design and performance approval for an appliance, system, or product. However, the TSO does not provide procedures for installation approval or procedures for design or implementation of an installation. With heightened interest by manufacturers and operators to equip transport category airplanes with TAWS systems that are compliant with TSO-C151, the FAA has recognized the need to establish guidance material for the design and test requirements for the installation of such systems. This Advisory Circular (AC) has been developed as the means for providing such guidance.

This AC describes the airworthiness considerations for designing a TAWS installation. The airworthiness considerations discussed apply only to the interface of the TAWS with other aircraft systems on transport category airplanes.

5. DISCUSSION.

a. Regulatory Basis. New [*proposed*] requirements under 14 CFR parts 91, 121,and 135 require the installation of the TAWS. Specifically:

(1) **§ 91.223** states that no person may operate a turbine-powered U.S.-registered airplane configured with 6 or more passenger seats, excluding any pilot seat, unless that airplane is equipped with an approved terrain awareness and warning system that meets the requirements of Class B equipment of TSO-C151.

(2) **§ 121.354** states that no person may operate a turbine-powered airplane unless that airplane is equipped with an approved terrain awareness and warning system, including a terrain awareness display, that meets the requirements for Class A equipment of TSO-C151.

(3) **§ 135.154** states that no person may operate a turbine-powered U.S.-registered airplane configured with 6 to 9 passenger seats, excluding any pilot seat, unless that airplane is equipped with an approved terrain awareness and warning system that meets the requirements of Class B equipment of TSO-C151. It also states that no person may operate a turbine-powered U.S.-registered airplane configured with 10 or more passenger seats, excluding any pilot seat, unless that airplane is equipped with a terrain awareness and warning system that meets the provisions of Class A equipment of TSO-C151.

(4) The [*proposed*] parts 121 and 135 regulations also mandate that GPWS be replaced with a TAWS approved under TSO-C151.

b. System Criticality. It has been FAA's policy to categorize systems that are designed to alert the flightcrew of potentially hazardous operating conditions as being at a level of criticality associated with a probable failure condition. This is because the failure of these systems themselves is not considered to hamper safe flight and landing. Typically, these systems had a failure probability of 1.0×10^{-3} or less per flight hour, and the associated hazardous level was categorized as minor, in accordance with Advisory Circular (AC) 25.1309-1A, *System Design and Analysis*. These systems did not take into account, however, the likelihood that a warning would be needed or that nuisance alerts may cause the flightcrew to rely less on the system.

There have been recent CFIT accidents in which a GPWS was installed in the accident airplane and was operational, but because of the older, less reliable systems, or because of a stressful, high workload situation on the flight deck, the flightcrews either ignored the GPWS alerts or failed to notice them. As stated previously, CFIT is the major contributor to commercial jet airplane hull losses and fatalities. In order for the TAWS to be effective in helping to reduce the CFIT accident rate, it must provide a clear and concise awareness to the flightcrew during adverse operating conditions.

In order to ensure this, the applicant must demonstrate that the TAWS possesses a level of reliability commensurate with systems that have a failure probability of 10^{-4} or less per flight hour. The system's reliability should be established by quantitative analysis, using guidance provided in AC 25.1309-1A, or by another equivalent method.

6. SYSTEM DESCRIPTION. TAWS is intended to provide flightcrews with aural and visual alert aids aimed at preventing a CFIT accident through increased terrain awareness.

a. Class A TAWS equipment as defined in TSO-C151.

(1) **Class A TAWS equipment provides three principal alerting functions**. These are:

(a) *Forward-Looking Terrain-Avoidance (FLTA) function*, which includes:

- Reduced required terrain clearance.
- Imminent terrain impact.

(b) *Premature Descent Alert (PDA) function.*

(c) *Basic Ground Proximity Warning System (GPWS) functions*, as defined in TSO-C151 and RTCA Document DO-161A, which include:

- Excessive rates of descent.
- Excessive closure rate to terrain.
- Negative climb rate or altitude loss after take-off.
- Flight into terrain when not in landing configuration.
- Excessive downward deviation from and ILS glideslope.
- Descent of the airplane to 500 feet above the terrain or nearest runway elevation (voice callout "Five Hundred").

(2) **The Class A TAWS system will require a display**. The terrain display and terrain-threat alerting are made possible by the TAWS' acceptance of a variety of input parameters. These parameters are used in conjunction with a terrain and airport database(s) that reside within the TAWS computer. The Class A TAWS places an airplane symbol on a digital terrain map and applies terrain display algorithms. Terrain mapping information may be provided on either a weather radar (WXR) display, Electronic Flight Instrument System (EFIS) display, or other compatible display screens. Aircraft position information is provided by either the Flight Management Computer (FMC), Global Positioning System (GPS), or other source of positional information that meets the requirements specified in section 7.e.(2)(a) of this AC.

b. Class B TAWS equipment, as defined in TSO-C151.

(1) **Class B TAWS equipment provides three principal alerting functions**. These are:

(a) *FLTA function*, which includes:

- Reduced required terrain clearance
- Imminent terrain impact

(b) *Premature Descent Alert (PDA) function*

(c) *Basic GPWS functions*, as defined in TSO-C151 and RTCA Document DO-161A, which include:

- Excessive rates of descent
- Negative climb rate or altitude loss after take-off
- Descent of the airplane to 500 feet above the terrain or nearest runway elevation (voice callout "Five Hundred").

(2) **The Class B TAWS will not require a display**. If a display is installed with a Class B TAWS, it should meet the requirements of section 7.g. of this AC.

7. AIRWORTHINESS CONSIDERATIONS.

a. Certification Program. The scope of the applicant's program should be directed toward airworthiness approval through the Type Certification (TC) or Supplemental Type Certification (STC) process. The guidance provided in this AC also is appropriate for applicants who choose to exercise their Designated Alteration Station (DAS) authorization for STC approval. As part of the amended TC or STC program, the applicant must identify if the changes to the type certificated airplane constitute a significant change, but not one so extensive as to require a new TC in accordance with § 21.19 (*Changes Requiring a New Type Certificate)*. If the design change is considered significant, the certification program must be coordinated with the responsible FAA Directorate, as described in FAA Order 8110-4A, *Type Certification*.

On January 25, 1999, the FAA, in coordination with the Aerospace Industries Association (AIA) and the General Aviation Manufacturers Association (GAMA), introduced *The FAA and Industry Guide to Product Certification*. This aid communicates the design and production certification process for aircraft. It describes how to plan, manage, and document an effective and efficient product certification process. A crucial part of this process is the development of a Project Specific Certification Plan (PSCP).

b. Project Specific Certification Plan (PSCP). The applicant should develop a comprehensive PSCP that includes the following:

(1) **Project Description:** A summary of the project.

(2) **System Description**

(a) A comprehensive system description that includes a brief summary of the product as it relates to existing flight deck displays, sensors, added sensors, electrical components, interior arrangement, other interfaces, product part number, etc.

(b) A layout and description of any changes to the flight instrument panels and flight engineer panels.

(c) Information regarding software aspects of certification and any application-specific integrated circuits (ASIC).

(3) **Project Schedule**

(a) A detailed project schedule that identifies all major milestones and schedules for any required deliverables (i.e., test plans).

(b) Schedules for operational and maintenance aspects, as well as foreign authority validation requirements.

(4) **Certification Basis and Means of Compliance**

(a) A certification matrix that identifies the applicable regulations, AC's, current policies, certification basis, and the procedures or methods that will be used to comply with those regulations.

(b) Any testing or analyses applicable to the project that have been previously approved by the FAA under an STC, TC, TSO, or Parts Manufacturer Approval (PMA) held by the applicant. The approval date, letter reference number, and references as to how the specific approval was granted (i.e., STC, TSO, letter of approval, etc.) should be included in this section.

(5) **Communication and Coordination**

(a) If applicable, identification of all Designated Engineering Representatives (DER) or Designated Alteration Station (DAS) specialists working on the program.

(b) Identification of all delegated functions, which should include any stipulations, coordination, and limitations that are placed upon those delegations.

(6) **Testing Plan**. This section should contain the requirements for the planning, preparation, and conduct of FAA required testing, including any delegations

(7) **Compliance Documentation.** This section should describe the procedures for submittal and processing of compliance documentation.

c. System Safety Assessment.

(1) A system safety assessment (SSA) should be performed that establishes the hazards associated with the proposed installation. The SSA should be developed in accordance with AC 25.1309-1A and Society of Automotive Engineers (SAE) Aerospace Recommended Practice (ARP) 4761, *Guidelines and Methods for Conducting the Safety Assessment Process on Civil Airborne Systems and Equipment.*

(2) The FAA expects an SSA for the installation to establish the probability of system failure, false alerts, and unannunciated failures. Given that TSO-C151 requires 10^{-5} for unannunciated failure, HMI, and false alerts at the box level, the box as installed must meet the following criteria:

(a) The probability of failure of the installed system to perform its intended function from a reliability/availability perspective, as described in section 6.a. and 6.b., above, shall be less than or equal to 10^{-3} per flight hour.

(b) The probability of a false caution and/or warning alert shall be less than or equal to 10^{-4} per flight hour.

(c) The probability of an unannunciated failure of the system to provide the required alerting functions shall be less than or equal to 10^{-4} per flight hour.

(d) The probability of the system to provide hazardously misleading information (HMI) to the TAWS display shall be less than or equal to10^{-4} per flight hour.

(e) Failure of the installed TAWS shall not degrade the integrity of any essential or critical system installed in the airplane with which the TAWS interfaces.

d. Software. The applicant must verify that the TAWS software meets the requirements of TSO-C151.

e. Position Source. TAWS uses the estimated position of the airplane with reference to the terrain/obstacle to determine when an alert should be annunciated. Accordingly, the applicant should consider the following:

(1) **Accuracy**. The applicant should demonstrate that the accuracy of the TAWS position source is suitable for each phase of flight (i.e., enroute, remote/oceanic, terminal, and approach) for which approval is sought.

(2) **Previously-Approved Navigational Systems**.

(a) Class A equipment that uses an RNAV system may be used to determine the TAWS airplane position, provided that:

- It previously has been approved for navigation in accordance with the guidance contained in TSO-115; AC 90-45A (*Approval of Area Navigation Systems for Use in the U.S. National Airspace System)* for approved required navigation (RNAV) systems; TSO-C129a for GPS; and TSO-C145 for Wide Area Augmentation System (WAAS).

  or

- It follows the recommendations in AC 20-130A *(Airworthiness Approval of Navigation or Flight Management Systems Integrating Multiple Navigation Sensors)* and/or AC 20-138 *(Airworthiness Approval of Global Positioning System Navigation Equipment for Use as a VFR and IFR Supplemental Navigation System).*

A means for testing the position source for accuracy and reliability is unnecessary for these systems.

(3) **Self –Contained GPS Navigator Function**. Class A and Class B equipment that use a GPS internal to the TAWS for horizontal position information, and that are capable of detecting a positional error that exceeds the appropriate alarm limit for the existing phase of flight, in accordance with DO-208 or equivalent, are considered acceptable. When this alarm limit is activated, the GPS-computed position is considered unsuitable for the TAWS, and a TAWS unavailability indication should be provided. A means for verifying the position source for accuracy is necessary for these systems.

f. Terrain Database. The terrain database for TAWS has been validated via the TSO-C151 authorization process, so there is no need to revalidate the database during the installation process. However, there are two areas of concern that must be addressed during the installation process:

(1) **Updates**. The installed system must be capable of accepting updated terrain databases (and obstacle databases as well, if included). The TAWS manufacturers must have a procedure in place whereby the manufacturer can inform the airplane owner/operator about updates, or the airplane owner/operator can learn about updates. The procedure must contain sufficient information to enable the owner/operator to make a logical safety decision as to whether it is appropriate to purchase and install the update.

(2) **Valid Regional Data**. The applicant must verify that the TAWS terrain database includes terrain and airport information for the area of intended operation.

g. Display Presentation

NOTE: A terrain display is not mandatory for Class B equipment (see sections 6.b. of this AC and TSO-C151, for further definition).

(1) **Terrain Display**.

(a) TSO-C151 does not address a TAWS with its own display hardware. Instead, any device approved under TSO-C151 must be capable of providing terrain, obstacle, and alerting data to display hardware that is already onboard the airplane, such as a weather radar (WXR), an Electronic Flight Instrument System (EFIS) display, or other compatible display system. The actual display presentation format that the flightcrew sees will depend on the onboard display hardware, the options made available by the TSO-C151 manufacturer, and the features desired by the customer/user. Regardless of whatever format is used, the display presentation must enhance the flightcrew's terrain situational awareness.

(b) The terrain display system is a subsystem of the TAWS; therefore, the possibility of failure of that system should be no greater than 10^{-3} per average flight hour, and the possibility of misleading information on the display should be no greater than 10^{-4} per average flight hour.

(c) The applicant should consider the potential for, and any hazards associated with, the flightcrew's use of the display to confirm all TERRAIN alerts (i.e., caution or warning). To evaluate this potential misuse of the display, a representative sample of pilots should participate in the development and evaluation process for the proposed presentation format (if practical and not already done on some previous certification project).

(2) **Terrain Display Presentation**. TAWS equipment shall be designed to interface with a Terrain Display, either color or monochromatic. The terrain display shall be capable of providing the following terrain-related information:

(a) The terrain shall be depicted relative to the airplane's position such that the pilot may estimate the relative bearing to the terrain of interest.

(b) The terrain shall be depicted relative to the airplane's position such that the pilot may estimate the distance to the terrain of interest.

(c) The terrain depicted shall be oriented to either the heading or track of the airplane. In addition, a North-up orientation may be added as a selectable format.

(d) Variations in terrain elevation depicted relative to the airplane's elevation (above and below) shall be visually distinct. Terrain that is more than 2000 feet below the airplane's elevation need not be depicted.

(e) Terrain that generates alerts shall be displayed in a manner to distinguish it from non-hazardous terrain, consistent with the caution and warning alert level.

(f) The terrain display presentation should be clear, unambiguous, and readily usable by the flightcrew during day and night operations under all ambient lighting conditions expected in service.

(g) The terrain display should be viewable in direct sunlight, and at least one display must be viewable by each pilot.

(h) A failed and/or inoperative TAWS should be indicated to the flightcrew in a manner consistent with the flight deck design philosophy.

(i) The terrain display presentation should complement and be compatible with the terrain alerting function of the TAWS.

(j) Terrain mapping should allow the flightcrew to determine relative terrain elevation.

(k) The terrain display should be designed so that the flightcrew can readily determine if terrain is a threat to the airplane.

(l) The colors and/or textures used for threat terrain should be intuitive and indicate the immediacy of the threat.

(m) If the terrain is presented on a shared display, the terrain mode and terrain information should be easily distinguishable from weather and other features.

(n) The selected colors should complement the discreet visual and aural alerts that are presented to the flightcrew. Accordingly, any colors that are used for the threat terrain display should match the colors used for the discreet visual alerts.

(3) **Pop-Up Mode-Switching Functionality.**

(a) *General Considerations*. If implemented, an automatic pop-up feature should incorporate the following considerations in its design:

- The pop-up functionality should automatically display TAWS-related information when a TAWS caution alert occurs.
- The pop-up functionality should be implemented consistently for weather and traffic alerts.

- The display system should be designed so that it is very evident that an automatic pop-up has occurred.
- The terrain display mode should be annunciated on the display.
- Manually switching back to the original mode of operation should require minimal effort.

(b) *Pop-Up Inhibit Feature*. For dual displays, pop-up functionality can be inhibited if the terrain map is on at least one display when a terrain alert occurs. However, if the terrain map is not on a display when a terrain alert occurs, the terrain map, with the alerts, should be automatically displayed on both the left and right displays.

(c) *Prioritizing Pop-Up Displays Between Systems.* In installations where the TAWS and the Predictive Windshear System (PWS) share the same display, and automatic pop-up functionality is employed, the display priorities indicated in Table 1, below, are recommended:

TABLE 1. ***Prioritization of pop-up displays where the TAWS and the Predictive Windshear System (PWS) share the same display***

Priority		Description
Highest	1	Terrain Awareness Warning
	2	Predictive Windshear Warning
	3	Terrain Awareness Caution
	4	Predictive Windshear Caution
	5	Normal Terrain
Lowest	6	Weather Radar (Normal PWS)

If the system provides alerting for obstacle threats, the prioritization for warnings and cautions should be the same as those for terrain. The priorities are listed in the table above.

(4) **Auto-Range Switching Mode**. An auto-ranging function is not required. However, if provided, an auto-ranging display should be designed so that it is very evident to the flightcrew that the range has been automatically selected. The range selected for auto-ranging should provide a usable depiction of the threat on the display. Switching back to a manually-selected range should require minimal effort.

h. Alerts. Alerts should be clear, concise, and unambiguous. (Refer to TSO-C151 for further definition of alerting.) The alerting system should be:

(1) Consistent with the alerting philosophy of the airplane flight deck in which the TAWS equipment is installed; and

(2) Within the flightcrew's primary field of view.

i. Alert Prioritization.

(1) Installations of TAWS on aircraft also equipped with a Reactive Windshear System (RWS), Predictive Windshear System (PWS), and Traffic Alert and Collision Avoidance System (TCAS) should include an aural prioritization scheme such that:

(a) Only one aural alert is given at any one time, and

(b) Aural alerts for situations requiring immediate action by the flightcrew have priority in situations where conditions for multiple alerts may occur.

(2) Implementing this prioritization scheme within the TAWS equipment is acceptable. Table 2, below, displays an example of the recommended voice prioritization:

TABLE 2. ***Recommended voice prioritization between the TAWS and other systems installed***

Priority		Description
Highest	1	Reactive Windshear Warning
	2	Sink Rate Pull-Up Warning *(Excessive Rates of Descent)*
	3	Terrain Closure Pull-Up Warning *(Excessive Closure Rates)*
	4	Terrain Awareness Pull-Up Warning *(FLTA)*
	5	Predictive Windshear Warning
	6	Minimums *(Voice Callouts)*
	7	Terrain Awareness Caution *(FLTA)*
	8	Too Low Terrain *(Flight Into Terrain When Not in Landing Configuration)*
	9	PDA ("Too Low Terrain") Caution *(FLTA)*
	11	Altitude Callouts *(Voice callouts)*
	12	Too Low Gear *(Flight Into Terrain When Not in Landing Configuration)*
	13	Too Low Flaps *(Flight Into Terrain When Not in Landing Configuration)*
	14	Sink Rate *(Excessive Rates of Descent)*
	15	Don't Sink *(Negative Climb Rate or Altitude Loss After Take-off)*
	16	Glideslope *(Excessive Downward Deviation From an ILS Glideslope)*
	17	PWS Caution
	18	Approaching Minimums *(Voice Callouts)*
	19	Bank Angle *(Voice Callouts)*
	20	Reactive Windshear Caution
	21	TCAS RA ("Climb," "Descend," etc.)
Lowest	22	TCAS TA ("Traffic, Traffic")

Note:
- Voice Callouts are allowed simultaneously with TCAS.
- If simultaneous aural alerts can be given, then the words must be understandable.

j. System Inhibit. Inhibiting the FLTA and PDA functionality should not impact the Basic GPWS functions. Appropriate annunciation of the inhibited functions must be provided to the flightcrew. Flightcrew procedures for disabling various TAWS functions should be identified in the Airplane Flight Manual (AFM).

k. Flight Data Recorder. For those applications that require crash-survivable flight data recording in accordance with the requirements of § 25.1459(e) (*Flight recorders*), a means should be provided to record the FLTA alerts in the same manner as is currently done for the Basic GPWS. It is not necessary to distinguish between Basic GPWS and the new FLTA and PDA alerts. A means also should be provided to record a FLTA and/or PDA-inhibit.

l. Human Factors. The applicant should address human factors issues as part of its certification program, and provide human factors support for decisions regarding the flightcrew interface issues resulting from the TAWS installation.

m. Flight Test Requirements

(1) There are many factors that will affect the flight test requirements of a specific vendor's TAWS equipment in a particular airplane. The principle installation related inputs to TAWS may vary significantly from airplane to airplane. Some of these variations include the following:

(a) Different altimeter sources;

(b) Different air data computer vendors;

(c) Different data bus architectures or different data input rates;

(d) Different radio altitude vendors;

(e) Different glideslope vendors;

(f) Different navigation system vendors;

(g) Different navigation system performance;

(h) FMS versus GPS;

(i) Different TAWS display vendors;

(j) Different TAWS display interface (stand-alone, integrated with ND or WX Radar, etc.)

(k) Different TAWS discrete annunciators, switches, or controls; and

(l) Different pin selectable options, such as "Pop Up."

(2) The following "cases" are intended to assist in determining the flight test requirements for some potential or likely TAWS configurations:

(a) *Case 1*. This is the first time the vendor's equipment has been installed in any airplane for the purpose of receiving a first time TC/STC approval. If such is the case, then a complete and thorough Ground and Flight Test program should be conducted to verify the adequacy of the installation.

(b) *Case 2*. This involves a follow-on installation of a previously approved TAWS in which a required sensor input has not been previously approved for the specific vendor's equipment. For example, if the sensor that provides barometric altitude (or equivalent) to the TAWS equipment has not been previously approved, the flight test evaluation should focus on the TAWS functions affected by barometric altitude such as FLTA and PDA.

(c) *Case 3*. This involves a follow-on installation of a previously approved TAWS in which the Terrain Display has not been previously approved. In this case, the focus of the flight test evaluation should be on display related issues and tests specified in paragraph 7.m.(6), below, of this AC.

(d) *Case 4*. This involves a follow-on installation of a previously approved TAWS in which the navigation source sensor input has not been previously approved for the specific vendor's equipment. In this case the focus of the flight test evaluation should be on the adequacy of the navigation source and the display of the terrain as determined by that navigation source. In addition, since the navigation system provides track and ground speed information to TAWS which affect the alerting logic, an FLTA functional flight test evaluation test is warranted.

(e) *Case 5*. This involves a follow-on installation of a previously approved TAWS in which the radio altitude to the TAWS equipment has not been previously approved. In this case, the focus of the flight test evaluation should be on the TAWS functions affected by radio altitude such as one of the Basic GPWS modes or the PDA function. Only one test is required to assure that the radio altimeter input is properly installed to the TAWS.

(f) *Case 6*. This involves an initial installation of a vendor's TAWS in an airplane that was previously approved with Basic GPWS equipment (per C-92) from the same vendor and the same sensors that are used for the GPWS installation are used for the TAWS installation. If such is the case, then Basic GPWS testing is not required to be accomplished for the TAWS installation.

FLIGHT TEST MATRIX

TAWS Functions	*Case 1*	*Case 2*	*Case 3*	*Case 4*	*Case 5*	*Case 6*
FLTA	X	X	X	X		X
PDA	X	X			X or	X
BASIC GPWS *	X				X	
TERRAIN DISPLAY	X		X	X		X
TAWS NAVIGATION SOURCE	X			X		X

* *Class A equipment*

(3) **FLTA Flight Test Requirements**.

(a) Flight testing to verify the proper operation of the FLTA function can be conducted in an area where the terrain or obstacle elevation for the test runs is known within approximately 300 feet. Two test runs are recommended:

- one in level flight at approximately 500 feet above the terrain/obstacle of interest, and
- another while descending toward the terrain/obstacle of interest.

(b) In each case, the Terrain Display can be evaluated, the specific terrain cells that cause the alert can be evaluated, the aural and visual alerts can be evaluated, the navigation source input can be evaluated, and the terrain data base can be evaluated.

NOTE: The terrain selected should be at least 15 NM from the nearest airport to conduct the test as described. If this is not practical, the fly-over altitude will have to be lowered to 300 feet or less above the terrain/obstacle in order to generate a TAWS alert.

(4) **PDA Flight Test Requirements**. Flight testing to verify the proper operation of the PDA function can be conducted in any airport area within 10 NM of the nearest runway. The airplane should be configured for landing at approximately 1500 feet AGL along the final approach segment of the runway at approximately 10 NM from the runway. At the 10 NM point, a normal three degree flight path angle descent can be initiated and maintained until the PDA alert occurs.

NOTE: The runway selected for this test should be relatively free from terrain/obstacles to preclude activation of the FLTA function. Approximately level

terrain along the final approach segment will exercise the PDA function. This test may also exercise the 500 foot voice callout. The adequacy of the PDA aural alert should be verified during this test. This test will also verify the adequacy of the airport data base, the navigation source input and the barometric and/or radio altitude inputs to TAWS.

(5) **Basic GPWS Flight Test Requirements**. Flight testing to verify the proper operation of Basic GPWS functions can be conducted in any area where the terrain elevation is known to the flight crew. The following information is intended to provide guidance for conducting flight tests to exercise and verify the proper operation of each GPWS function. The need to conduct flight testing for follow-on TAWS installations will depend upon the nature of the new or modified sensors and their impact on that particular GPWS function.

(a) *Excessive Rates of Descent*. This test can be conducted at any location but descents toward near level terrain are recommended for best results and ease of correlation with DO-161 envelopes. For Class A equipment, exercising this test verifies the proper installation of barometric altitude (and the corresponding computation of barometric altitude rate) and radio altitude. For Class B equipment, exercising this test verifies the proper installation of barometric altitude, the height above terrain as determined from the GPS position and the corresponding terrain elevation from the terrain data base. Only one test run is required to determine proper installation.

(b) *Excessive Closure Rate To Terrain.* This test must be conducted in an area of known rising terrain. It is recommended that one level test run at an altitude between 500-1000 feet above the terrain elevation be conducted. For Class A equipment only, this test will verify the proper installation of the radio altimeter.

(c) *Negative Climb Rate or Altitude Loss After Takeoff.* This test is conducted immediately after takeoff before climbing above 700 AGL or above runway elevation. For Class A equipment, exercising this test verifies the proper installation of barometric altitude, barometric altitude rate and radio altitude. For Class B equipment, exercising this test verifies the proper installation of barometric altitude and height above terrain as determined from the GPS position and the corresponding terrain elevation from the terrain data base.

(d) *Flight Into Terrain When Not In Landing Configuration.* This test should be conducted while on a visual approach to a runway. For Class A equipment only, exercising this test verifies the proper installation of barometric altitude, barometric altitude rate and radio altitude as well as the gear and flap sensor inputs to TAWS.

(e) *Excessive Downward Deviation From an ILS Glideslope.* This test should be conducted during an ILS approach. For Class A equipment only, this test will verify the proper installation of the ILS Glideslope input to TAWS.

(f) *Voice Callout "Five Hundred Feet."* This test is conducted during an approach to a runway. For Class A and B equipment, this test will verify the proper installation of barometric altitude, radio altitude, and height above terrain as determined by either radio altitude or by access to the terrain data base.

(6) **Terrain Display Flight Test Requirements.** Flight testing to verify the proper operation of the Terrain Display should be conducted while verifying all the other required TAWS functions. Emphasis should be placed on verifying compliance with the requirements specified in Terrain Presentation section of the advisory circular during normal airplane maneuvering during all phases of flight. Pop-up and auto-ranging features should be evaluated if applicable. It is recommended to perform sustained turns to evaluate symbol stability, flicker, jitter, display update rate, color cohesiveness, readability, the use of color to depict relative elevation data, caution and warning alert area depictions, map masking and overall suitability of the display.

n. Airplane Flight Manual (AFM)/Airplane Flight Manual Supplement (AFMS**)**. The applicant should make an evaluation to determine if there are any limitations of the system and, if so, how they will affect aircraft operations. Any limitations affecting operations shall be included in the AFM/AFMS. As a minimum, the applicant should provide instructions in the Limitations Section of the AFM/AFMS that include the following:

(1) **Limitations**. The following instructions should be included in the Limitations section of all AFM/AFMS:

(a) Navigation must not be predicated upon the use of the TAWS.

NOTE: The Terrain Display is intended to serve as a situational awareness tool only. It may not provide the accuracy and/or fidelity on which to solely base decisions and plan maneuvers to avoid terrain or obstacles.

(b) To avoid giving unwanted alerts, the TAWS must be inhibited when landing at an airport that is not included in the airport database.

(c) The use of the terrain awareness warning and terrain display functions is prohibited during QFE (atmospheric pressure at airport elevation) operations.

NOTE: This limitation may not apply to systems that use other sources of altitude measurement to determine the airplanes vertical position.

(2) **Restricted Areas of Operation**. Areas of operation or other factors that adversely affect navigation performance to the extent that the TAWS will be potentially unreliable or misleading, should be identified in the AFM/AFMS. Areas of operation where the Terrain Data Base resolution or accuracy leads to nuisance alerts should also be identified.

(a) This situation may occur if:

- The data are not properly analyzed,
- There is not enough data to map the terrain adequately,
- The resolution of the data is not adequate for the type of approved position source, or
- There are changes in the area (volcanoes, earthquakes, construction) that have not been noted.

(b) A route structural analysis (RSA) may be needed to identify those airports or runways that are susceptible to nuisance alerts. This analysis can be accomplished by computer simulation. Engine-out procedures also should be considered when developing the RSA.

(3) **Operational Considerations for Normal/Abnormal Procedures.** In addition to the GPWS operational procedures, consider the following:

(a) *Terrain Awareness Caution*. When a terrain awareness CAUTION occurs, verify the airplane flight path and correct it, if required. If in doubt, perform a climb until the CAUTION alert ceases.

(b) *Terrain Awareness Warning*. If a terrain awareness WARNING occurs, immediately initiate and continue a climb that will provide maximum terrain clearance, or any similar approved vertical terrain escape maneuver, until all alerts cease. Only vertical maneuvers are recommended, unless operating in visual meteorological conditions (VMC), and/or the pilot determines, based on all available information, that turning in addition to the vertical escape maneuver is the safest course of action.

(c) *Cold Weather*. For operations in cold weather, either the system should be able to account for variations in cold weather at temperatures at or below 0° Celsius, or additional flightcrew procedures should be considered to address pressure altitude limits for vertical position determination. Limitations may be needed to address insufficient determination of the airplane's vertical position in cold weather temperatures.